2014 Concrete Materials Laboratory Test Study

A laboratory test study examining the plastic properties of concrete mixes at normal (20°C) and cold temperatures (5°C)

Concrete Floor Contractors Association

CFLRA

April 24, 2015

INDEX

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INTRODUCTION

In an effort to better understand the effect of site temperatures on concrete materials, the CFCA undertook a limited laboratory test study to observe the plastic & hardened properties of 5 different concrete mixes at both normal (20°C) and cold (5°C) temperatures.

This was a very small study conducted in laboratory conditions. Due to budget limitations, only 5 mixes were tested to compare plastic and hardened concrete properties over a wide range of cementing material types and proportions (there are more cementitious types which could have also been tested).

The following concrete mixes were selected for testing:

1. 25 MPa “compressive strength” mix using GU cement [160W/240GU].
2. 25MPa & 0.55 w/c mix using GU cement [160W/290GU].
3. 25MPa & 0.55 w/c mix using GUL cement [160W/290GUL].
4. 25MPa & 0.55 w/c HVSCM1 GU/S cement [160W/145GU&145S].
5. 25MPa & 0.55 w/c with reduced water, reduced GU cement and a plasticizer [145W/265GU+Plasticizer].

Note:

a) Type “GU” General Use cement is composed of Portland Cement with up to 5% Portland cement replacement with limestone. Type “GUL” General Use Limestone cement includes up to 15% inter-ground limestone Portland cement replacement.
b) Mixes 2 through 5 are CSA A23.1 compliant for ‘interior concrete floors with a steel trowel finish’. Mix 1 does not meet the CSA A23.1 mandatory requirements as the water:cement ratio exceeds a maximum ratio of 0.55.

All mixes had less than the 3% entrapped air except for the Plasticized Mix 5 which exhibited a higher plastic air content (3.4% vs 2.6% for all other non-plasticized mixes).

The effect of substituting GU cement with increasing percentages of flyash and slag was not studied except for Mix 4 (HVSCM1 with 50% slag). The increasing replacement of GU cement with slag or flyash would likely produce similar observations between GU Mix 2 and HVSCM Mix 4 (eg: slower 7d strength gain etc.).

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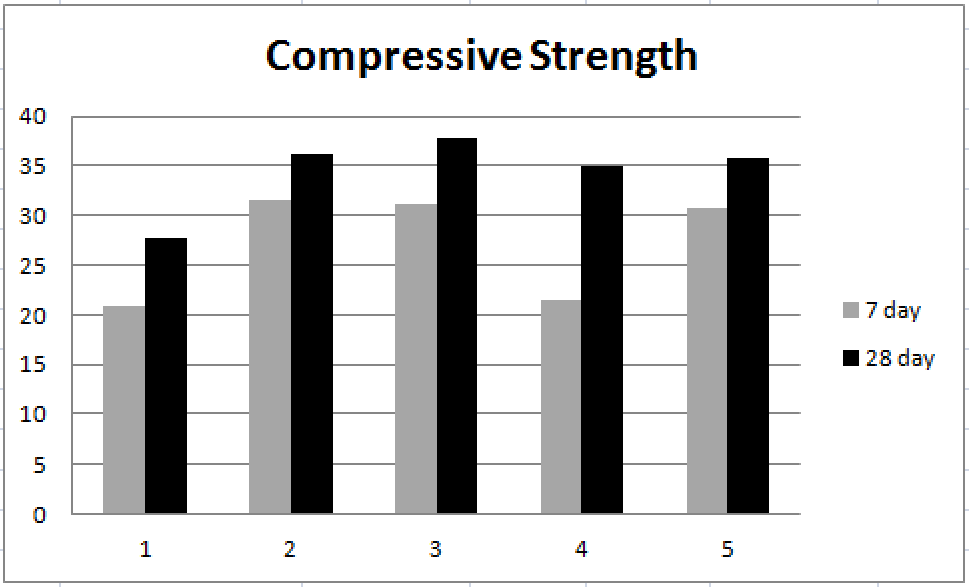

Figure 1: Compressive strength as per CSA A23.2-9C

Compressive strengths (f'c) varied depending upon the type and quantity of cementitious materials. Note: Compressive strength testing was not performed on the 5°C specimens but an extended period of strength gain would be anticipated.

The f'c Mix 1 & HVSCM Mix 4 had the lowest 7d compressive strengths. Mix 1 also had the lowest 28d compressive strength (due to lower GU cement content).

It is considered 'normal' when the 7 day "lab" compressive strength of concrete is approximately 75% of the 28 day strength (75%@7d). This was exactly the case for f'c Mix 1. For the 0.55 w/c mixes, GU Mix 2, GUL Mix 3 & Plasticized Mix 5 exhibited faster 7day strength gain (85%@7d average). HVSCM Mix 4 had the lowest percentage 7 day strength (61%@7d).

Plasticized Mix 5 had similar, but slightly lower, compressive strength results to the other 0.55 w/c GU & GUL cement (Mixes 2 & 3) with 9% less GU cement.

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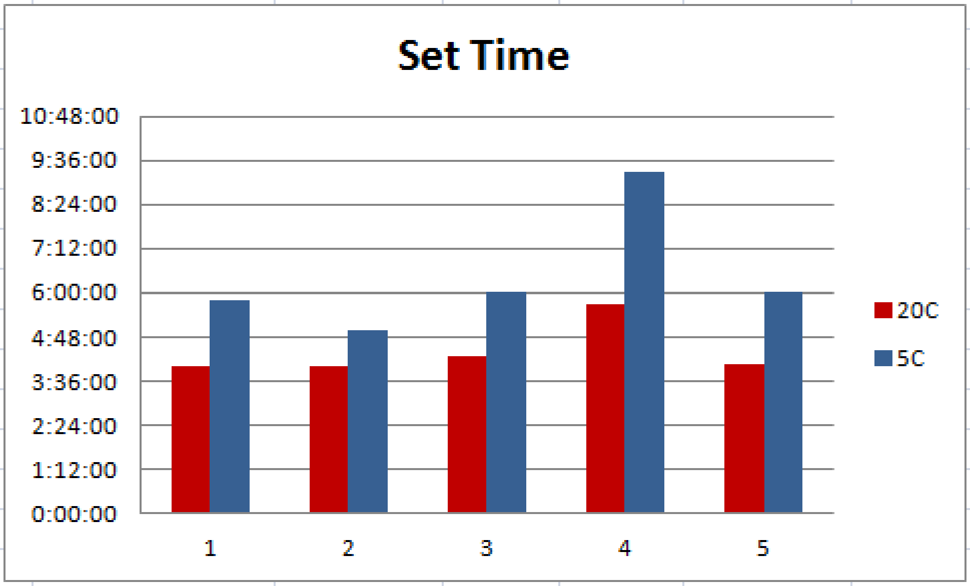

Figure 2: Set time at 20°C & 5°C as per ASTM C403

The set time varied by cement type and temperature.

With the exception of the HVSCM Mix 4, all mixes exhibited similar set times of approx. 4 hours at normal temperatures (HVSCM Mix 4 had a 40% higher set time). There was more variability in set times at cold temperatures than normal temperatures. Cold temperature set time was similar for Mixes 1, 2, 3, & 5. The HVSCM Mix 4 exhibited the largest increase in set time at 5°C (+63%).

Mix 2 had the lowest percentage variation in set time at 5°C (+25%) than all other mixes (range +40% to +60%).

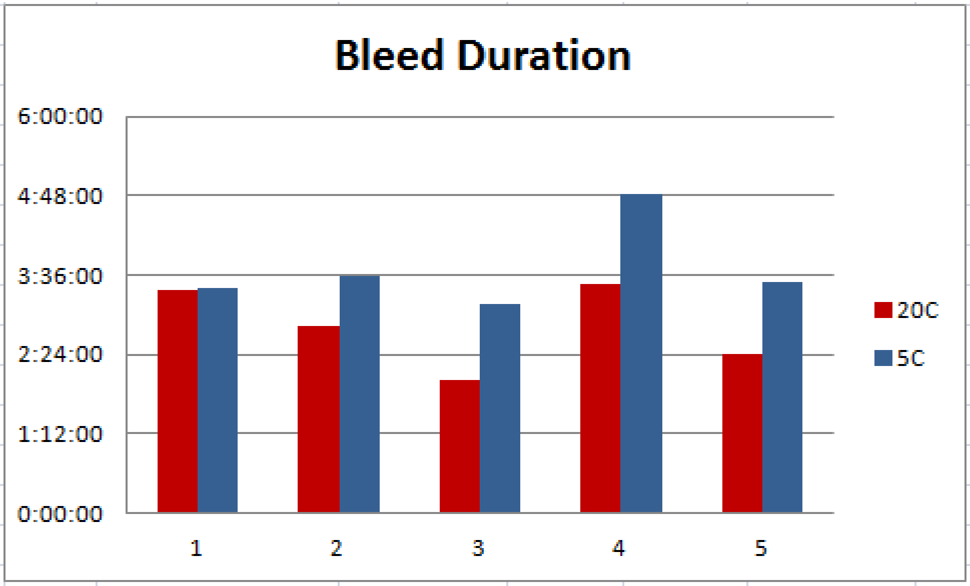

Figure 3: Bleed duration at 20°C & 5°C as per ASTM C232 (Method A)

The Bleed Duration varied by cement type and temperature.

At 20°C the bleed duration of all mixes varied from 47% to 84% of the set time (64% average). At 5°C the bleed duration was similar and varied between 52% to 72% of the set time (57% average).

F'c Mix 1 had a bleed duration of 84% of its set time at normal temperatures but this was reduced to 58% of its set time at cold temperatures (-30%).

Of the 0.55 w/c mixes, GU Mix 2 had the lowest increase in bleed duration at cold temperatures (+26% / identical to its set time increase). While GUL Mix 3 had the shortest bleed duration at normal temperatures (-30% vs GU), it had the highest % increase in bleed duration at cold temperatures (+58%).

The HVSCM Mix 4 had the largest absolute increase in bleed duration at low temperatures (1:22), followed by GUL Mix 3 (1:10), Plasticized Mix 5 (1:05) and GU Mix 2 (0:45).

Of the 0.55 w/c mixes (Mixes 2 to 5), GU Mix 2 had identical bleed duration vs set time at both normal and cold temperatures (72%) making this ideal in terms of consistency for concrete finishers in cold temperatures.

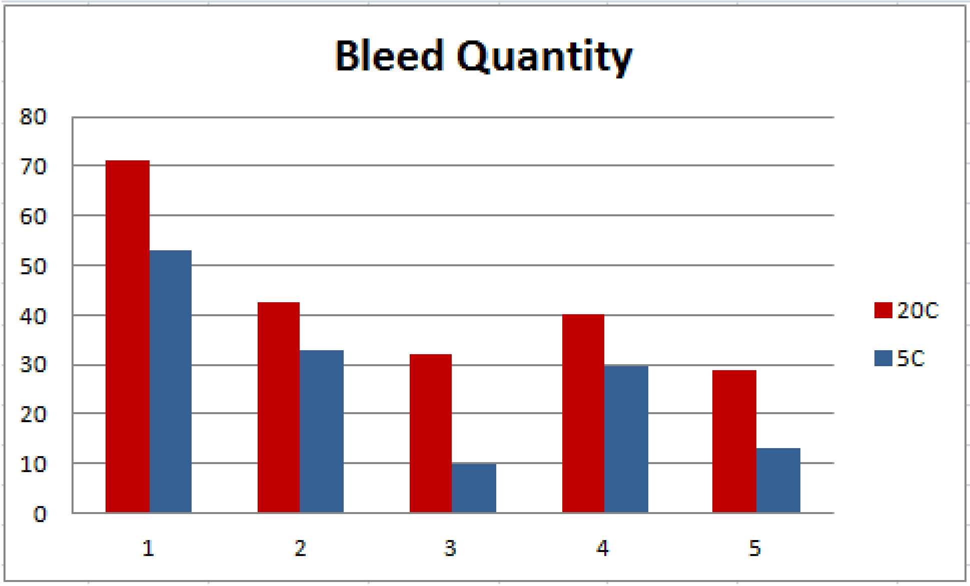

Figure 5: Bleed quantity at 20°C & 5°C as per ASTM C232 (Method A)

The Bleed Quantity varied by cement type and temperature.

F'c Mix 1 had the highest bleed quantity and a significantly greater bleed quantity than GU Mix 2 at both normal (+67%) and cold temperatures (+60%).

Of the 0.55 w/c mixes, GU Mix 2 & HVSCM Mix 4 exhibited similar bleed quantities at both normal and cold temperatures (-22 and -26% respectively). The bleed duration of HVSCM Mix 4 was higher than GU Mix 2 at both normal and cold temperatures (+22 & +34% respectively).

GUL Mix 3 and Plasticized Mix 5 both exhibited significantly reduced bleed quantity at 5°C (-69% & -55% respectively). Note that a 9% reduction in water & cement contents (Plasticized Mix 5 vs GU Mix 2) resulted in a 60% reduction in bleed quantity at 5°C. GUL Mix 3 and Plasticized Mix 5 would not be ideal for cold temperature concrete floor construction due to their very high water retention (higher risk of mix water entrapment).

A 20% increase (+50kgs/m3) in GU cement quantity (Mix 2 vs Mix 1) resulted in a 40% reduction in bleed quantity at both 20°C and 5°C. The addition of GU cement to obtain the 0.55 w/c substantially reduced the bleed quantity.

Note that the density of water is greatest at 4°C and that the viscosity of water increases by 50% (gets thicker) at 5°C vs 20°C.

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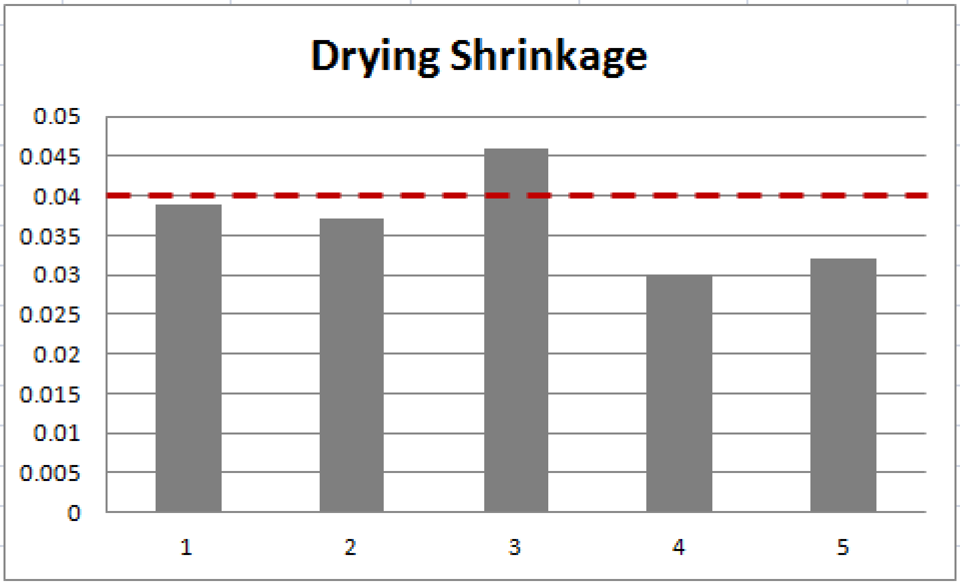

Figure 6: Drying shrinkage as per ASTM C157

Drying shrinkage varied based upon cement type.

Drying shrinkage is a critical performance consideration for lightly reinforced slabs on grade, slabs on metal deck and bonded concrete toppings. Concrete drying shrinkage also correlates to the magnitude of drying shrinkage curling in slabs on grade as well (a major problem).

While water content and aggregate gradation are perceived as the most important factor in controlling drying shrinkage, the cement type appears to play a major role as well. Even though mixes 1-4 had identical water contents, drying shrinkage varied considerably based upon cement type. Mixes 2, 3 & 4 had identical water and cementitious materials contents but had very different drying shrinkage results as well.

Mix 1 had a much higher w/c than Mix 2 yet achieved similar drying shrinkage results (Note: f'c Mix 1 exhibited variable results).

With the exception of GUL Mix 3, all mixes qualified as "low shrinkage" concrete as per CSA A23.1 (75mm specimens = max 0.04% @ 28d). This is confounding as mixes 1-4 were not designed to have lower drying shrinkage.

GUL Mix 3 did not qualify as "low shrinkage" and had greater drying shrinkage of all mixes (25% greater than GU Mix 2).

Extended drying shrinkage measurements were not taken after the 28 day readings. An extended drying duration could potentially exhibit different shrinkage results over time (relationship to joint width opening and the timing of joint filling in slabs on grade).

SUMMARY

1. The plastic properties of concrete mixes varied significantly based upon the type of cement being used, the cement quantity and the temperature of the concrete materials.
2. All mixes bled less in quantity at 5°C than 20°C (Range: -22 to -69%). This water retention caused by cold temperatures requires greater consideration. While all mixes were negatively affected by cold temperatures, GU Mix 2 was least affected in terms of set time, bleed duration and bleed quantity.
3. The need to ensure adequate site temperatures is critical to reduce concrete mix water retention. In addition to air temperature, the temperature of the supporting substrate (eg: granular base or steel deck) must also be maintained so as not to entrap mix water abnormally (Note: CSA A23.1 minimum 10°C temperature requirements).
4. Mixes 2-5 bled 35% less in quantity on average than f'c Mix 1 (GU Mix 2 bled 40% less than f'c Mix 1). The higher bleed quantity of compressive strength Mix 1 increases the propensity for water entrapment when combined with cold temperatures (higher free water quantity = greater probability of water entrapment at cold temperatures).
5. While GUL Mix 3 and Plasticized Mix 5 had good performance at 20°C, they had much lower performance in terms of bleed quantity at 5°C (-69% & -55% respectively). This mixes would not be ideal in cold temperatures.
6. The use of a plasticizer to reduce water and cement consumption at any given w/c is perceived as very beneficial in sustainable and business terms. While Plasticized Mix 5 with 9% less GU cement & water achieved approximately the same performance as GU Mix 2 at 20°C, it had poor performance at 5°C in terms of set time and bleed quantity (due to lower GU cement content). Concrete mixes require more GU cement in cold temperatures to obtain a normal set (eg: GU Mix 2 vs Plasticized Mix 5).
7. Surprisingly, with the exception of GUL Mix 3, all mixes qualified as "low shrinkage" in accordance with CSA A23.1 (requires consideration). GUL Mix 3 had the highest drying shrinkage which would not be ideal for lightly reinforced slabs on grade, slabs on metal deck and bonded concrete toppings. Extended drying shrinkage testing could be valuable to better understand the development of drying shrinkage curling and the timing of joint filling in slabs on grade.
8. The entrapped air content of Plasticized Mix 5 was higher than the 3% maximum limit for a machine trowel finish (3.4%). This highlights the important need for plastic air testing at the point of concrete placement. Further study on the effect of plasticizers on plastic air contents is highly recommended.

End of Report

CSA A23.1-2014 EXCERPT

Clause 8.12 Concrete mixes for interior concrete floors

Interior concrete floors with a steel trowelled finish, other than residential concrete floors (Class R-3 exposure, Table 1), are designated N-CF class of exposure (Table 2) and shall be designed to a maximum 0.55 w/cm and a minimum compressive strength of 25 MPa at 28 d (as specified in Table 2), as well as designed for placing methods finishability, set, and serviceability, as required for intended service.
Notes:
(1) See ACI 302 for further information on concrete slabs and concrete mixes.
(2) The water content of the concrete mix should be minimized to reduce the effects of shrinkage and the slump increased using a normal setting plasticizing admixture.
(3) Mixes most suited for floors should have a minimum slump of 100 mm at the point of placement. Higher workability or flow should be achieved with the addition of plasticizing admixture only.
(4) SCM use and chemical admixtures in concrete mixes can reduce the amount of bleed water available at the concrete surface unless other changes are made to the mix to address bleed rate. A reduction in available bleed water at the surface can create difficulties in finishability and in the application of dry shake surface hardeners and may increase the need to protect the slab from rapid evaporation of surface moisture. See Clause 7.5.
(5) The use of air entrained concrete is not recommended for interior ice rink slabs and freezer slabs with a steel trowelled finish. They have been found to perform satisfactorily without entrained air if an adequate period of drying is provided before the initial freezing.

Both the maximum 0.55 w/c and the minimum 25 MPa compressive strength are mandatory requirements under CSA A23.1 (not optional). See Clause 4.1.1.1.3.

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September 10, 2014

Ms. Geoff Kinney
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via email: gkinney@concretefloors.ca

Re: BRM-00603440-A0

Concrete Testing Report
Floor Mixes

Dear Mr. Kinney:

As requested, **exp** Services Inc. **(exp)** has completed our testing of the five concrete mixes agreed to for this program. The program involved testing five concrete mixes with differing mix proportions to determine if there were differences in various concrete parameters between the mixes. Also including in the program were samples from each mix tested for fresh concrete parameters at two different temperatures; at 20˚C and at 5˚C. The goal of this testing was to determine what differences existed between concretes placed at the different temperatures for the following parameters (test protocol used):

- Compressive Strength (CSA A23.2-9C)
- Setting time (ASTM C403)
- Time of bleeding (ASTM C232, Method A)
- Quantity of bleed water produced (ASTM C232, Method A)
- Shrinkage (ASTM C157)

The bleed tests were performed covered as required, both at room temperature and refrigerated, except during visual review and water extraction. This would reduce the potential for evaporation that would affect the test results. We actually purchased a new refrigerator for this project and installed a thermometer to monitor the temperature. The temperature varied between 3˚C and 7˚C.

This information would provide valuable data to both the floor finishers and to the concrete suppliers that would assist them in providing the highest quality floors placed in varied weather conditions.

The mixes were produced with the following materials:

- Coarse aggregate – Nelson Aggregates
- Fine Aggregate – Stouffville Sand
- Type GU Cement – Essroc
- Type GUL Cement – St. Marys

- Slag Cement – GranCem 100 cement, Holcim
- Plasticizer – Sikament 686, Sika

The mix designs were chosen to simulate those that could be used on projects and are shown in Table 1 and highlight the variations that were tested in our program.

The test results are shown in Table 2 and include compressive strength, setting and bleeding at both 20°C and 5°C and shrinkage at 28 days. We have previously supplied you with the actual bleed rate results as requested.

We trust the above is satisfactory; however, if we can be of any further assistance, please do not hesitate to contact this office.

Yours truly,

exp Services Inc.

Ammanuel Yousif, CET
Concrete Laboratory Supervisor
Earth & Environment

Peter Waisanen, P.Eng.
Concrete Specialist
Earth & Environment

Table 1 – Mix Designs

Mix #	Mix Designation	Details
1	25 MPa f'c	160W/240GU (0.67)
2	0.55 w/c	160W/290GU
3	0.55 w/c "GUL"	160W/290GUL
4	0.55 w/c HVSCM	160W/145GU+145S
5	0.55-W+P	145W/263GU+P

Table 2

Floor Mix – Test Results

Mix #	Comp. Str., 7- day (MPa)	Comp. Str., 28 – day (MPa)	Setting Time @ 20˚C (Hr:Min)	Bleed Amount @ 20˚C (ml)	Bleed Time @ 20˚C (Hr:Min)	Setting Time @ 5˚C (Hr:Min)	Bleed Amount @ 5˚C (ml)	Bleed Time @ 5˚C (Hr:Min)	Shrinkage @ 28 days (%)
1	20.8	27.7	4:01	71	3:22	5:49	53	3:24	0.039
2	31.5	36.1	4:00	42.5	2:50	5:00	33	3:35	0.037
3	31.1	37.8	4:16	32	2:00	6:01	10	3:10	0.046
4	21.4	34.9	5:41	40	3:28	9:17	29.5	4:50	0.030
5	30.7	35.7	4:02	29	2:25	6:02	13	3:30	0.032

All mixes tested had things in common when looking at the 2 different temperatures.

- All mixes bled less at 5˚C than at 20˚C
- All mixes took longer to set at 5˚C than at 20˚C
- All mixes had longer bleed times at 5˚C than at 20˚C

Mix 4 took the longest to set and also had the lowest shrinkage.

Mix 1 had the lowest strength and the highest bleed amount at both temperatures.